

## Appendix I: Details of Handsheet Study for Hudson Web Gloss

Table I.1

Case	Filler %	Kraft %	Groundwood %	Refining (CSF)
1 (control)	8	58	42	600
2	6	55	45	550
3	10	55	45	550
4	6	63	37	550
5	10	63	37	550
6	6	55	45	630
7	10	55	45	630
8	6	63	37	630
9	10	63	37	630

Case 10: Same as control, case 1, but cold calendered (steel-to-steel) to 556 pli

Case 11: Same as control, case 1, but cold calendered (steel-to-steel) to 1111 pli

## Appendix II: Data for Determining Fracture Toughness Based on the E. W. F. Approach

We present here the data for fracture energies for the tested samples, along with standard deviations and normalized fracture energies.

Table II.1: Fracture energy and related data for tested handsheets

Sample label	Sample Sub-label	Comments	Number of samples	L (mm)	t (mm)	B.W. (gsm)	Wf (J)	Wf - S.D. (J)	Wf/(Lt) (J/mm <sup>2</sup> )
Case 1A	MD10	Control	10	10	0.105	41.4	0.011	0.001	0.0104861
	MD15		6	15	0.102	41.4	0.018	0.001	0.0117119
	MD20		6	20	0.105	41.8	0.026	0.001	0.0123576
	MD25		6	25	0.106	42.7	0.037	0.003	0.013936
	CD10		10	10	0.103	42.1	0.004	0	0.0038747
	CD15		6	15	0.109	43.7	0.008	0.001	0.004902
	CD20		6	20	0.103	41.6	0.011	0.001	0.0053218
	CD25		6	25	0.105	43.1	0.019	0.002	0.0072206
1B	MD10	Repeat	10	10	0.100	39.4	0.01	0.001	0.0099966
	MD15		6	15	0.100	39.9	0.02	0.003	0.0133118
	MD20		6	20	0.109	45.3	0.028	0.002	0.0128832
	MD25		6	25	0.099	40.8	0.038	0.004	0.0153244
	CD10		10	10	0.103	41.2	0.005	0.001	0.0048767
	CD15		6	15	0.101	39.7	0.009	0.001	0.0059493
	CD20		6	20	0.108	45.4	0.014	0.002	0.006476
	CD25		6	25	0.107	43.4	0.018	0.001	0.0067297
1C	MD10	Repeat	10	10	0.104	42.6	0.012	0.001	0.0115332
	MD15		6	15	0.102	41.6	0.019	0.002	0.0123793
	MD20		6	20	0.102	42.3	0.027	0.002	0.0131922
	MD25		6	25	0.097	39.2	0.034	0.003	0.0140595
	CD10		10	10	0.103	43.5	0.006	0.001	0.0058297
	CD15		6	15	0.103	42.5	0.008	0.001	0.0051817
	CD20		6	20	0.101	41.9	0.012	0	0.0059352
	CD25		6	25	0.100	41.2	0.016	0.002	0.0063844
Case 2	MD10		10	10	0.101	42.1	0.012	0.001	0.0118582
	MD15		6	15	0.100	41.8	0.021	0.002	0.0139814
	MD20		6	20	0.102	41.6	0.031	0.002	0.0152644
	MD25		6	25	0.102	41.7	0.04	0.002	0.0156181
	CD10		10	10	0.101	41.5	0.005	0	0.0049593
	CD15		6	15	0.101	41.5	0.008	0.001	0.0052875
	CD20		6	20	0.099	39.7	0.012	0.001	0.0060468
	CD25		6	25	0.101	41.2	0.017	0.001	0.0067473
Case 3	MD10		10	10	0.106	43.8	0.011	0.001	0.0103746
	MD15		6	15	0.104	43.0	0.018	0.001	0.0115121
	MD20		6	20	0.098	39.6	0.024	0.001	0.012289
	MD25		6	25	0.103	42.5	0.035	0.003	0.0136054
	CD10		10	10	0.103	41.5	0.004	0.001	0.0038974
	CD15		6	15	0.105	43.1	0.007	0	0.0044546
	CD20		6	20	0.098	39.5	0.011	0.001	0.005639
	CD25		6	25	0.105	43.4	0.016	0.001	0.0060788
Case 4	MD10		10	10	0.097	39.9	0.012	0.001	0.0123496
	MD15		6	15	0.100	40.9	0.021	0.002	0.0139991
	MD20		6	20	0.097	40.4	0.031	0.001	0.0159915
	MD25		6	25	0.103	42.3	0.04	0.003	0.0155728
	CD10		10	10	0.101	41.8	0.005	0.001	0.0049639
	CD15		6	15	0.100	40.7	0.01	0.001	0.0066402
	CD20		6	20	0.098	40.5	0.012	0.001	0.0061277
	CD25		6	25	0.100	40.6	0.018	0.002	0.0071712
Case 5	MD10		10	10	0.104	43.8	0.012	0.001	0.011568

Table II.1: Continued

Sample label	Sample Sub-label	Comments	Number of samples	L (mm)	t (mm)	B.W. (gsm)	Wf (J)	Wf - S.D. (J)	Wf/(Lt) (J/mm <sup>2</sup> )
Case 1A	MD10	Control	10	10	0.105	41.4	0.011	0.001	0.0114861
Case 5	MD10		10	10	0.104	43.8	0.012	0.001	0.011568
	MD15		6	15	0.105	42.9	0.02	0.002	0.0127565
	MD20		6	20	0.102	42.3	0.028	0.002	0.0137432
	MD25		6	25	0.100	41.4	0.034	0.003	0.0135341
	CD10		10	10	0.100	41.8	0.005	0	0.0050064
	CD15		6	15	0.105	43.1	0.008	0.001	0.0050944
	CD20		6	20	0.101	42.9	0.012	0.001	0.0059378
	CD25		6	25	0.103	41.3	0.015	0.002	0.0058511
Case 6	MD10		10	10	0.107	41.6	0.012	0.001	0.0112415
	MD15		6	15	0.108	42.9	0.02	0.002	0.0123577
	MD20		6	20	0.107	41.3	0.029	0.003	0.0135959
	MD25		6	25	0.106	40.6	0.037	0.002	0.0139638
	CD10		10	10	0.109	43.7	0.006	0.001	0.005499
	CD15		6	15	0.112	42.9	0.009	0	0.0053701
	CD20		6	20	0.104	40.4	0.012	0.001	0.0057616
	CD25		6	25	0.102	42.3	0.017	0.002	0.0058333
Case 7	MD10		10	10	0.111	43.8	0.011	0.001	0.0099214
	MD15		6	15	0.109	42.7	0.017	0.002	0.0103914
	MD20		6	20	0.107	42.0	0.024	0.001	0.0111789
	MD25		6	25	0.112	43.9	0.036	0.003	0.0128072
	CD10		10	10	0.105	42.6	0.004	0.001	0.0037968
	CD15		6	15	0.109	42.3	0.007	0.001	0.0042976
	CD20		6	20	0.105	41.5	0.011	0.001	0.0052268
	CD25		6	25	0.109	42.5	0.016	0.001	0.0058901
Case 8	MD10		10	10	0.109	43.2	0.014	0.002	0.0127985
	MD15		6	15	0.105	42.2	0.021	0.002	0.0132708
	MD20		6	20	0.106	42.4	0.031	0.003	0.0145818
	MD25		6	25	0.107	42.9	0.045	0.004	0.0168484
	CD10		10	10	0.104	40.6	0.005	0.001	0.0047978
	CD15		6	15	0.105	41.8	0.009	0.002	0.0056997
	CD20		6	20	0.101	40.2	0.013	0.001	0.0064172
	CD25		6	25	0.105	42.5	0.02	0.002	0.0076158
Case 9	MD10		10	10	0.107	43.2	0.011	0.002	0.0102608
	MD15		6	15	0.106	43.5	0.019	0.002	0.0119606
	MD20		6	20	0.104	42.8	0.027	0.004	0.01293
	MD25		6	25	0.105	42.1	0.033	0.002	0.0125728
	CD10		10	10	0.114	42.2	0.005	0.001	0.0043933
	CD15		6	15	0.106	42.9	0.009	0.001	0.0056753
	CD20		6	20	0.105	43.0	0.012	0.002	0.0057334
	CD25		6	25	0.104	41.3	0.015	0.001	0.0057606
Case 10A	MD10	Repeat of Case 1	10	10	0.110	43.3	0.011	0.001	0.0100379
	MD15		6	15	0.105	42.8	0.019	0.002	0.0120377
	MD20		6	20	0.102	41.4	0.025	0.002	0.0122828
	MD25		6	25	0.104	41.6	0.035	0.003	0.0135057
	CD10		10	10	0.108	43.3	0.005	0.001	0.0046094
	CD15		6	15	0.105	42.7	0.008	0.001	0.0050664
	CD20		6	20	0.101	41.5	0.012	0.001	0.0059177
	CD25		6	25	0.103	41.2	0.016	0.001	0.0062018
Case 10B	MD10	Repeat of Case 1	10	10	0.105	42.1	0.011	0.001	0.0105243
	MD15		6	15	0.105	42.1	0.019	0.001	0.0121187
	MD20		6	20	0.104	42.5	0.026	0.003	0.0124613
	MD25		6	25	0.100	40.1	0.033	0.002	0.0132009
	CD10		10	10	0.101	39.3	0.004	0	0.0039791
	CD15		6	15	0.104	41.4	0.007	0.001	0.0044921
	CD20		6	20	0.103	40.8	0.012	0.001	0.0058174
	CD25		6	25	0.106	41.8	0.016	0.002	0.0060448

Table II.1: Continued

Sample label	Sample Sub-label	Comments	Number of samples	L (mm)	t (mm)	B.W. (gsm)	Wf (J)	Wf - S.D. (J)	Wf/(Lt) (J/mm <sup>2</sup> )
Case 11	MD10	Case 1	10	10	0.063	41.5	0.009	0.002	0.0142473
	MD15	calendered	6	15	0.065	42.3	0.019	0.004	0.0194418
	MD20	to 556 pli	6	20	0.065	41.9	0.024	0.003	0.0183234
	MD25		6	25	0.063	41.5	0.038	0.001	0.024256
	CD10		10	10	0.062	41.1	0.004	0.001	0.0064931
	CD15		6	15	0.063	41.7	0.009	0.001	0.0094759
	CD20		6	20	0.063	40.5	0.013	0.002	0.0102591
	CD25		6	25	0.064	42.4	0.018	0.002	0.0112588
Case 12	MD10	Case 1	10	10	0.054	42.1	0.006	0.001	0.0111198
	MD15	calendered	6	15	0.053	41.9	0.01	0.002	0.0126219
	MD20	to 1111 pli	6	20	0.054	41.3	0.014	0.002	0.0129518
	MD25		6	25	0.052	39.1	0.015	0.002	0.0115322
	CD10		10	10	0.054	41.6	0.003	0.001	0.0055809
	CD15		6	15	0.051	41.8	0.005	0	0.006495
	CD20		6	20	0.052	42.2	0.007	0.001	0.0066836
	CD25		6	25	0.051	40.0	0.009	0.001	0.0071181

Table II.2: Normalized fracture energies for handsheet study

Sample label	Sample Sub-label	Comments	Wf/(Lt) (kJ/m <sup>2</sup> )	Wf/(L*B.W.) (J.m/kg)	Wf/(L*B.W.) (S.D.)
Case 1A	MD10	Control	10.49	26.57	2.42
	MD15		11.71	29.01	1.61
	MD20		12.36	31.11	1.20
	MD25		13.94	34.66	2.81
	CD10		3.87	9.49	0.00
	CD15		4.90	12.21	1.53
	CD20		5.32	13.22	1.20
	CD25		7.22	17.62	1.85
1B	MD10	Repeat	10.00	25.39	2.54
	MD15		13.31	33.42	5.01
	MD20		12.88	30.89	2.21
	MD25		15.32	37.22	3.92
	CD10		4.88	12.15	2.43
	CD15		5.95	15.11	1.68
	CD20		6.48	15.41	2.20
	CD25		6.73	16.61	0.92
1C	MD10	Repeat	11.53	28.15	2.35
	MD15		12.38	30.47	3.21
	MD20		13.19	31.90	2.36
	MD25		14.06	34.69	3.06
	CD10		5.83	13.79	2.30
	CD15		5.18	12.55	1.57
	CD20		5.94	14.32	0.00
	CD25		6.38	15.55	1.94
Case 2	MD10		11.86	28.51	2.38
	MD15		13.98	33.49	3.19
	MD20		15.26	37.26	2.40
	MD25		15.62	38.37	1.92
	CD10		4.96	12.04	0.00
	CD15		5.29	12.85	1.61
	CD20		6.05	15.11	1.26
	CD25		6.75	16.52	0.97
Case 3	MD10		10.37	25.10	2.28
	MD15		11.51	27.89	1.55
	MD20		12.29	30.30	1.26
	MD25		13.61	32.94	2.82
	CD10		3.90	9.65	2.41
	CD15		4.45	10.82	0.00
	CD20		5.64	13.92	1.27
	CD25		6.08	14.76	0.92
Case 4	MD10		12.35	30.08	2.51
	MD15		14.00	34.20	3.26
	MD20		15.99	38.35	1.24
	MD25		15.57	37.83	2.84
	CD10		4.96	11.95	2.39
	CD15		6.64	16.37	1.64
	CD20		6.13	14.81	1.23
	CD25		7.17	17.72	1.97
Case 5	MD10		11.57	27.38	2.28

Table II.2: Continued

Sample label	Sample Sub-label	Comments	Wf/(Lt) (kJ/m <sup>2</sup> )	Wf/(L*B.W.) (J.m/kg)	Wf/(L*B.W.) (S.D.)
Case 1A	MD10	Control	10.49	26.57	2.42
Case 5	MD10		11.57	27.38	2.28
	MD15		12.76	31.06	3.11
	MD20		13.74	33.10	2.36
	MD25		13.53	32.86	2.90
	CD10		5.01	11.95	0.00
	CD15		5.09	12.37	1.55
	CD20		5.94	13.98	1.17
	CD25		5.85	14.54	1.94
Case 6	MD10		11.24	28.85	2.40
	MD15		12.36	31.06	3.11
	MD20		13.60	35.14	3.63
	MD25		13.96	36.45	1.87
	CD10		5.50	13.72	2.29
	CD15		5.37	13.99	0.00
	CD20		5.76	14.85	1.24
	CD25		6.27	16.08	1.89
Case 7	MD10		9.92	25.11	2.28
	MD15		10.39	26.52	3.12
	MD20		11.18	28.57	1.19
	MD25		12.81	32.83	2.74
	CD10		3.80	9.40	2.35
	CD15		4.30	11.03	1.58
	CD20		5.23	13.26	1.21
	CD25		5.89	15.06	0.94
Case 8	MD10		12.80	32.42	4.63
	MD15		13.27	33.16	3.16
	MD20		14.58	36.54	3.54
	MD25		16.85	41.96	3.73
	CD10		4.80	12.33	2.47
	CD15		5.70	14.35	3.19
	CD20		6.42	16.17	1.24
	CD25		7.62	18.82	1.88
Case 9	MD10		10.26	25.47	4.63
	MD15		11.96	29.15	3.07
	MD20		12.93	31.53	4.67
	MD25		12.57	31.35	1.90
	CD10		4.39	11.85	2.37
	CD15		5.68	13.98	1.55
	CD20		5.73	13.95	2.33
	CD25		5.76	14.53	0.97
Case 10A	MD10	Repeat of Case 1	10.04	25.39	2.31
	MD15		12.04	29.57	3.11
	MD20		12.28	30.21	2.42
	MD25		13.51	33.65	2.88
	CD10		4.61	11.54	2.31
	CD15		5.07	12.49	1.56
	CD20		5.92	14.46	1.20
	CD25		6.20	15.55	0.97
Case 10B	MD10	Repeat of	10.52	26.14	2.38

Table II.2: Continued

Sample label	Sample Sub-label	Comments
Case 1A	MD10	Control
Case 10B	MD10	Repeat of
	MD15	Case 1
	MD20	
	MD25	
	CD10	
	CD15	
	CD20	
	CD25	
Case 11	MD10	Case 1
	MD15	calendered
	MD20	to 556 pli
	MD25	
	CD10	
	CD15	
	CD20	
	CD25	
Case 12	MD10	Case 1
	MD15	calendered
	MD20	to 1111 pli
	MD25	
	CD10	
	CD15	
	CD20	
	CD25	

Wf/(Lt) (kJ/m <sup>2</sup> )	Wf/(L*B.W.) (J.m/kg)	Wf/(L*B.W.) (S.D.)
10.49	26.57	2.42
10.52	26.14	2.38
12.12	30.09	1.58
12.46	30.58	3.53
13.20	32.92	2.00
3.98	10.18	0.00
4.49	11.27	1.61
5.82	14.69	1.22
6.04	15.32	1.92
14.25	21.71	4.83
19.44	29.94	6.30
18.32	28.64	3.58
24.26	36.66	0.96
6.49	9.74	2.43
9.48	14.39	1.60
10.26	16.04	2.47
11.26	16.98	1.89
11.12	14.26	2.38
12.62	15.91	3.18
12.95	16.96	2.42
11.53	15.36	2.05
5.58	7.21	2.40
6.49	7.97	0.00
6.68	8.30	1.19
7.12	9.00	1.00

## Appendix III

**Table III.1: Physical Properties of Test Samples**

Sample	Basis wt. (g/m <sup>2</sup> )	Thickness (mm)	Apparent density (g/cm <sup>3</sup> )	Extension at break (%)	Tensile strength (MPa)	Elastic modulus (MPa)	0.2% Yield stress (MPa)
Case 1 MD	42.9	0.104	0.415	2.761	30.7	2,667	19.7
Case 1 CD	42.9	0.104	0.415	2.285	9.3	895	7.3
Case 2 MD	43	0.105	0.410	2.377	30.7	2,850	20.2
Case 2 CD	43	0.105	0.410	2.051	10.2	989	8.3
Case 3 MD	42.1	0.100	0.422	2.474	30.4	2,726	19.6
Case 3 CD	42.1	0.100	0.422	2.243	9.3	917	7.4
Case 4 MD	40.3	0.100	0.402	2.023	30.3	2,877	20.7
Case 4 CD	40.3	0.100	0.402	2.408	11.4	1,177	8.8
Case 5 MD	43.4	0.102	0.425	2.283	31.4	2,719	21.6
Case 5 CD	43.4	0.102	0.425	2.831	10.4	1,018	7.7
Case 6 MD	42.5	0.109	0.391	2.350	30.0	2,646	20.0
Case 6 CD	42.5	0.109	0.391	2.038	9.2	916	7.2
Case 7 MD	41.6	0.106	0.391	2.405	24.6	2,274	17.1
Case 7 CD	41.6	0.106	0.391	1.902	8.8	909	7.1
Case 8 MD	42.5	0.103	0.411	2.569	30.8	2,742	19.1
Case 8 CD	42.5	0.103	0.411	2.134	9.9	1,015	7.9
Case 9 MD	41.1	0.102	0.403	2.460	26.5	2,483	17.3
Case 9 CD	41.1	0.102	0.403	1.996	8.6	919	6.6
Case10MD	41.5	0.063	0.658	2.242	38.9	3,705	26.7
Case10CD	41.5	0.063	0.658	2.680	13.7	1,083	9.2
Case11MD	41.3	0.057	0.727	0.718	24.3	4,421	
Case11CD	41.3	0.057	0.727	1.478	10.4	1,234	8.8

**Table III.2: Fracture Toughness Data**

Sample	Fracture toughness (J.m/kg)	Fracture toughness (R-squared)	Fracture toughness (MD/CD)	Ductility (=β*w <sub>p</sub> ) (J/g)
Case 1 MD	21.10	0.987	4.96	0.528
Case 1 CD	4.25	0.942		0.508
Case 2 MD	22.70	0.935	2.63	0.667
Case 2 CD	8.63	0.972		0.314
Case 3 MD	20.00	0.999	3.43	0.519
Case 3 CD	5.83	0.949		0.369
Case 4 MD	25.50	0.852	2.63	0.548
Case 4 CD	9.70	0.673		0.315
Case 5 MD	24.60	0.817	2.48	0.37



Case 5 CD	9.93	0.945		0.188
Case 6 MD	23.50	0.966	1.97	0.538
Case 6 CD	11.90	0.93		0.158
Case 7 MD	19.40	0.937	3.55	0.504
Case 7 CD	5.46	0.997		0.384
Case 8 MD	24.80	0.903	3.12	0.64
Case 8 CD	7.96	0.993		0.426
Case 9 MD	22.40	0.841	2.07	0.401
Case 9 CD	10.80	0.765		0.16
Case10MD	14.00	0.842	2.29	0.87
Case10CD	6.11	0.88		0.467
Case11MD	14.10	0.248	2.30	0.087
Case11CD	6.13	0.979		0.114

**Table III.3: Miscellaneous Strength-Related Properties**

Sample	Internal bond (10 <sup>-3</sup> ) (ft.-lbf)	Tear (gf)	Tear (MD/CD)	Stiffness (Gurley) (mgf)	Z-direction tensile (lb/in <sup>2</sup> )	Zero-span tensile (N/cm)	Formation index (Kajaani)
Case 1 MD	118	25.6	0.542	50.9	98	70.8	99
Case 1 CD	132	47.2		17.2	98	28	99
Case 2 MD	126	22.4	0.500	53.9	124	70.4	99.3
Case 2 CD	130	44.8		19	124	30.8	99.3
Case 3 MD	104	20.8	0.456	46.3	113	68.9	101
Case 3 CD	96	45.6		14.6	113	27.6	101
Case 4 MD	127	22.4	0.483	45.8	106	67	96
Case 4 CD	129	46.4		16.2	106	30.4	96
Case 5 MD	115	24	0.484	48.5	114	70.8	97.7
Case 5 CD	116	49.6		18.2	114	28.4	97.7
Case 6 MD	137	25.6	0.533	52.9	110	70	100.3
Case 6 CD	128	48		20.2	110	28.4	100.3
Case 7 MD	98	22.4	0.500	43.7	103	61.2	101.3
Case 7 CD	95	44.8		17.3	103	27.2	101.3
Case 8 MD	129	26.4	0.465	50.8	107	71.2	97.7
Case 8 CD	125	56.8		16.2	107	30.4	97.7
Case 9 MD	102	24	0.508	42.9	104	63.5	101
Case 9 CD	103	47.2		16.1	104	28.4	101
Case10MD	97	13.5	0.375	22.9	88	64.3	107.5
Case10CD	88	36		6.8	88	28	107.5
Case11MD	104	15	0.725	20.4	101	63	88.5
Case11CD	110	20.7		5.57	101	26.8	88.5